

**METHODS AND APPARATUS FOR REHABILITATION AND TRAINING****FIELD OF THE INVENTION**

The present invention relates to manipulation of a body, for example for physical rehabilitation and/or training.

**BACKGROUND OF THE INVENTION**

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After accidents or strokes, persons often need a prolonged rehabilitation process in an attempt to recapture some or all of the body function damaged in the accident or stroke. Such rehabilitation may include one or both of two elements, a physical rehabilitation portion, where damaged or unused muscles, nerves and/or joints are brought back to full functioning (to the extent possible) and a cognitive rehabilitation portion, where the cognitive ability to control the body is restored. In some cases, the damage to the body and/or brain is such that a patient needs to be trained in modified functionality (e.g., when one limb is made short) or even new functionality, for example, in the use of an artificial limb.

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Physical therapy is currently provided mainly by personal attention of a physical therapist who monitors and instructs a patient in the performance of certain exercises. Thus, costs for rehabilitation is high and compliance after a patient leaves a treatment center is relatively low.

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Some home physical therapy devices are known, for example a product called "backlife" provides CPM of the spine.

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US patent 5,836,304, the disclosure of which is incorporated herein by reference, describes a cognitive rehabilitation including a remote therapist.

**SUMMARY OF THE INVENTION**

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An aspect of some embodiments of the invention relates to a rehabilitation device which guides a patient to perform a motion with a correct spatial trajectory, by the device applying one or more pushing and/or resisting forces during a motion by the patient. In some embodiments, the applied forces act as a force field, optionally continuous, which impedes and/or guides a patient. Alternatively or additionally to spatial trajectories, orientation trajectories and/or speed trajectories are guided, supported and/or measured.

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In an exemplary embodiment of the invention, the device supports, for a given volume of space and a range of force strengths, substantially any 3D trajectory within that volume. In an exemplary embodiment of the invention, a device is provided which supports the range of motion of a healthy arm or leg in one two or three dimensions. In some cases, a partial volume is sufficient, for example, 50% or 30% of such a volume.

Optionally, the device is programmable with various trajectories and/or forces. Optionally, the forces at one point in the trajectory can vary responsive to an actual trajectory by the patient, possibly a same trajectory (e.g., at an earlier point thereof) and/or responsive to a rehabilitation plan and/or improvement of the patient. Optionally, the device learns the  
5 patient motion and repeats it with a correction (e.g. a smoothing of trajectory and or speed). Alternatively or additionally, the device can learn a motion entered by a physiotherapist motion and replay it for the patient, with an optional adjustment (e.g. a limb size adjustment).

In an exemplary embodiment of the invention, the programming comprises programming an electronic controller. In an exemplary embodiment of the invention, the  
10 programming comprises mechanical programming.

An aspect of some embodiments of the invention relates to a rehabilitation device adapted for home use. In an exemplary embodiment of the invention, the device is portable in a home, for example, not permanently attached to any surface. In an exemplary embodiment of the invention, the device is collapsible on a regular basis. In an exemplary embodiment of the  
15 invention, the device is light enough to avoid structural overloading of residential floors, for example the device can weigh less than 100kg, less than 50 Kg or less than 25Kg.

In an exemplary embodiment of the invention, the device ensures that a patient is correctly positioned. Optionally, the patient is notified to correct his position. In an alternative embodiment of the invention, the device recalibrates itself to take the patient position into  
20 account.

In an exemplary embodiment of the invention, the devices is usable (e.g., by programming or setting) for a plurality of different treatments, for example, a plurality of different body sizes, a plurality of different ages, a plurality of different joints and/or a plurality of different appendages.

25 An aspect of some embodiments of the invention relates to long term rehabilitation and/or training. In an exemplary embodiment of the invention, a rehabilitation device is used for a long period of time, for example, months or years. Optionally, a same device is used both for rehabilitation and for training of a patient in correct motions. In an exemplary embodiment of the invention, a rehabilitation device is used for preventive training, for example, ensuring  
30 that a patient with developing arthritis does not start favoring a diseased joint. Optionally, the device is used for non-medical training, for example as a universal gym machine.

An aspect of some embodiments of the invention relates to feedback for rehabilitation. In an exemplary embodiment of the invention, the feedback includes feedback on carrying out

of daily activities. Alternatively or additionally, the feedback includes feedback from a remote therapist or automatic feedback, during an activity. Alternatively or additionally, the feedback includes on a quality of the motion carried out by the patient.

5 An aspect of some embodiments of the invention relates to rehabilitation treatment methods. In an exemplary embodiment of the invention, training specifically in daily activities is carried out with the assistance of a rehabilitation device. Alternatively or additionally, training to prevent deterioration is provided, for example, to prevent deterioration of Parkinson's disease caused by neglecting of arm/function. Alternatively or additionally, training to provide long term improvement is carried out, for example, to provide improvement  
10 in cerebral palsy. Alternatively or additionally, treatment to prevent disease is carried out, for example, training a patient to not neglect a joint just because it hurts.

An aspect of some embodiments of the invention relates to using a rehabilitation device for both rehabilitation and testing, diagnosing and/or monitoring. In an exemplary embodiment of the invention, the device is used to asses the abilities of a patient and then to rehabilitation  
15 that patient. Alternatively or additionally, the device is used to measure the patient and calibrate future rehabilitation to those measurements. Exemplary measurements include size, strength, range of motion and motion quality.

An aspect of some embodiments of the invention relates to a rehabilitation method related to motion quality. In an exemplary embodiment of the invention, a quality of a motion  
20 is defined. Optionally, when a patient is being rehabilitated, automated feedback is provided to the patient regarding the quality of his motion. Alternatively or additionally, part of rehabilitation and/or training is teaching a patient the quality value for various motions.

An aspect of some embodiments of the invention relates to programming a rehabilitation device with a correct movement. In an exemplary embodiment of the invention,  
25 a correct motion is programmed into the device by performing the correct motion and then storing the motion in a device-associated memory. Optionally, the motion is programmed in during a dedicated teaching mode or when the device is off-line. Alternatively, the device learns during usage by a patient.

An aspect of some embodiments of the invention relates to a rehabilitation device for  
30 daily activities, in which the rehabilitation device is configured to train and/or test patients in the carrying out of daily activities. In an exemplary embodiment of the invention, the rehabilitation device can be used in proximity to real-life settings, such as a table or a counter.

An aspect of some embodiments of the invention relates to a rehabilitation method in

which a healthy body part is used for rehabilitating a diseased body part. In an exemplary embodiment of the invention, a rehabilitation device allows simultaneous or parallel motion of two limbs, one damaged and one not, and uses the correct motion of an undamaged limb as a basis for force field definition for the damaged limb. Alternatively or additionally, sequential  
5 motion by undamaged and then damaged limbs is provided. Optionally, the undamaged motion is modified, for example reduced in force, speed or range of motion. Optionally, the motion is mirror motion or synchronized motion (e.g., arm and leg during swimming). In an exemplary embodiment of the invention, a device which can hold two limbs is used. In some embodiments the motion of the two limbs is linked. In other embodiments, there is some or  
10 complete de-coupling between the limbs, at least in real time.

An aspect of some embodiments of the invention relates to a multi-point rehabilitation device in which the rehabilitation device is attached to a human body at multiple points which can move relative to each other, which motion is part of rehabilitation.

In an exemplary embodiment of the invention, the rehabilitation device attaches to two  
15 limbs, for example an arm and a leg or two arms.

In an exemplary embodiment of the invention, the rehabilitation device separately allows motion in 3D space of two bones on either side of a joint.

In an exemplary embodiment of the invention, the device mechanically limits motion for one or more of the points. Optionally, one or more of the points are tracked (in one or more  
20 dimensions) but their motion is not mechanically limited in some or any directions.

In an exemplary embodiment of the invention, the rehabilitation device supports complex motion in which different parts of the body are called upon to carry out certain motions, for example, shoulder motion and wrist motion.

An aspect of some embodiments of the invention relates to a mechanical structure for a  
25 rehabilitation device. In an exemplary embodiment of the invention, the device comprises an arm mounted on a joint, with a body attachment point, for attachment to or holding by a patient is mounted on the arm. The joint acts as a spherical joint, allowing movement of the arm along substantially any path on the surface of a sphere, within a range of angles, for example,  $\pm 90$  degrees relative to the center of the joint, in either of phi and theta directions (e.g., in spherical  
30 coordinates). Optionally, the center of rotation for such motions is substantially a same center of rotation for all the paths. In an exemplary embodiment of the invention, the joint and/or the arm as a whole lack singularity points in the range of motion. Optionally, the resistance to motion of the joint (the device may add resistance) is substantially uniform, substantially

independently of the spherical motion.

In an exemplary embodiment of the invention, the spherical joint comprises a ball in socket joint, with the arm attached to the ball or to the socket. The other one of the ball or socket is optionally attached to a base, for example, a base which stands on a floor or is  
5 attached to a wall or a ceiling.

Optionally, the device includes a weight attached to said ball opposite of said arm and serving to balance the motion of said arm. Optionally, the motion of the arm is substantially balanced over the entire range of motion thereof. In an exemplary embodiment of the invention, the balancing includes prevention of a resting torque. Alternatively or additionally,  
10 balancing includes correction for an existing moment of inertia or an expected moment of inertia during use. Optionally, the device is configured to include a resting force which tends to stabilize or destabilize the device, depending on the embodiment.

Optionally, one or more guiding plates are provided. In an exemplary embodiment of the invention, a pin attached to the ball, optionally part of the weight, is constrained to travel  
15 within a slot (e.g., a rectangle or other shape) defined in a guide plate. Optionally, the slot is elastic.

Optionally, one or more motors are provided to rotate the ball and/or apply force in a desired direction.

Optionally, one or more directional brakes are provided to selectively stop motion of  
20 the ball in a desired direction.

Optionally, one or more uni-directional brakes are provided to selectively stop motion of the ball in any direction.

In an alternatively embodiment of the invention, two or more joints having a shared center of rotation, are provided instead of a ball, for example a universal joint.

25 In an exemplary embodiment of the invention, the arm is extendible along its axis. Optionally, a motor is provided for selectively moving or apply force to resist motion of the extension along the axis. Optionally, one or more brakes are provided to selectively resist motion of said extension along said axis.

In an exemplary embodiment of the invention, the extension is balanced, so that it has  
30 no self motion. Alternatively or additionally, the extension, even when extended to various extents does not affect a balance of said arm.

Optionally, a rehabilitation device is positionable at various orientations. Optionally, the device includes a joint between its base and an articulating portion thereof.



An aspect of some embodiments of the invention relates to a ball joint with selective locking. In an exemplary embodiment of the invention, a chuck is provided to selectively lock rotation of the ball joint. Optionally, a plurality of directional brakes are provided. Optionally, one or more sensors generates an indication of a direction of force application and a controller  
5 elects which directional and/or uni-directional brakes to release responsive to the force direction.

An aspect of some embodiments of the invention relates to safety for a rehabilitation device. In an exemplary embodiment of the invention, the rehabilitation device includes one or more mechanical fuses which selectively tear when, shear, strain and/or torque on a  
10 replaceable element (such as a pin) increase above a threshold. Alternatively to a mechanical pin, an adjustable magnetic pin may be used, in which two parts of a pin attach to each other based on magnetic attraction. The attraction level is optionally set by moving a magnet inside one of the parts of the pin. Torque is optionally detected by providing a serrated connection between the pin parts which links relative rotation of the pin parts and separation of the parts.  
15 Optionally, a wire is provided in the pin so that tearing of the wire can be detected by the device electrically.

In an exemplary embodiment of the invention, a dead-man switch is provided for a patient in which if a patient lets go of the switch, the device stops or goes into a predefined or dynamically determined safe mode. Optionally, the dead-man switch is on a wireless element  
20 held by a good limb or body part, for example, being stepped on, held by hand or held in a mouth.

In an exemplary embodiment of the invention, a voice activated shut-off is provided, for example to allow a patient to stop the rehabilitation by shouting.

In an exemplary embodiment of the invention, the rehabilitation device analyses  
25 motions and/or forces applied by the patient, to detect problems. For example, any gross irregularities will cause the rehabilitation device to stop.

#### BRIEF DESCRIPTION OF THE FIGURES

Non-limiting embodiments of the invention will be described with reference to the following description of exemplary embodiments, in conjunction with the figures. The figures  
30 are generally not shown to scale and any sizes are only meant to be exemplary and not necessarily limiting. In the figures, identical structures, elements or parts that appear in more than one figure are preferably labeled with a same or similar number in all the figures in which they appear, in which:

Fig. 1 is a schematic showing of an articulated-arm based rehabilitation device, in accordance with an exemplary embodiment of the invention;

Fig. 2 is a schematic block diagram of a remote rehabilitation system, in accordance with an exemplary embodiment of the invention;

5 Fig. 3 illustrates a force field generated by a rehabilitation device in accordance with an exemplary embodiment of the invention;

Fig. 4A is a flowchart of a method of using a rehabilitation device, in accordance with an exemplary embodiment of the invention;

10 Fig. 4B is a flowchart of a long term use of a rehabilitation device, in accordance with an exemplary embodiment of the invention;

Fig. 5 illustrates a system including limb position sensing, in accordance with an exemplary embodiment of the invention;

Fig. 6 illustrates an elbow holding attachment, in accordance with an exemplary embodiment of the invention;

15 Fig. 7 and Fig. 8 illustrate two handle rehabilitation devices, in accordance with exemplary embodiments of the invention;

Figs. 9A and 9B illustrate devices for controlled motion of more than one point in a body, in accordance with exemplary embodiments of the invention;

20 Fig. 10 shows a ball-based rehabilitation device, in accordance with an exemplary embodiment of the invention;

Fig. 11 shows a balancing of the rehabilitation device of Fig. 10, in accordance with an exemplary embodiment of the invention;

Fig. 12 illustrates a drive system for a plate-based rehabilitation device, in accordance with an exemplary embodiment of the invention;

25 Fig. 13A illustrates a coupling device for a plate drive system, in accordance with an exemplary embodiment of the invention;

Fig. 13B illustrates a plate with a flexible slot, in accordance with an exemplary embodiment of the invention;

30 Fig. 14A illustrates a two plate rehabilitation device, in accordance with an exemplary embodiment of the invention;

Figs 14A and 14B illustrate guide plates in accordance with exemplary embodiments of the invention;

Fig. 15 shows a wrist attachment, which provides control and/or feedback for one or

more degrees of motion of a hand, in accordance with an exemplary embodiment of the invention;

Figs. 16A-16D illustrate various methods of elbow support in accordance with exemplary embodiments of the invention;

5 Fig. 17 illustrates a rehabilitation device with varying orientation, in accordance with an exemplary embodiment of the invention;

Fig. 18 shows a rehabilitation device for an arm and a leg, in accordance with an exemplary embodiment of the invention;

10 Fig. 19 shows a rehabilitation device for two sides of a body, in accordance with an exemplary embodiment of the invention;

Fig. 20 shows a chuck mechanism in accordance with an exemplary embodiment of the invention;

Fig. 21 shows an alternative non-ball, balanced, rehabilitation device, in accordance with an exemplary embodiment of the invention; and

15 Fig. 22 shows a rehabilitation device configured for use for daily activities, in accordance with an exemplary embodiment of the invention.

## DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

### General

20 The following description includes both methods of rehabilitation and devices suitable for effecting such methods. The organization used is first describing a single rehabilitation device and how it may be used and thereof describing a plurality of rehabilitation devices. It should be appreciated however, that the usage of the devices for certain methods of the present invention is not limited to the particular device used to illustrate a particular method.

### Articulated arm design

25 Fig. 1 is a schematic showing of an articulated-arm based rehabilitation device 100, in accordance with an exemplary embodiment of the invention.

30 Device 100 comprises an articulated arm 102 that projects upwards out of a table or other pedestal 104. Other exemplary general layouts are shown below. A tip 108 of arm 102 serves as a controlled point which can travel various 3D trajectories. Optionally, pedestal 104 is not attached to a floor but is instead weighted by a weight 106 (which may be located elsewhere than shown), to prevent tipping or capsizing of device 100 during use.

In an exemplary embodiment of the invention, arm 102 is an articulated arm, which support movement in 3D space. Alternative designs, for example based on a single joint and an



extending arm, are described below.

In an exemplary embodiment of the invention, arm 102 comprises a plurality of sections 110 interconnected by a plurality of joints 112. In an exemplary embodiment of the invention, each joint is motored, for example as known in the art of robotic arms. Alternatively or additionally, each joint is selectively lockable, for example as described below. Optionally, angular position sensors are provided at each joint and/or a position sensor at tip 108, so the position in space of arm 102 and/or of tip 108 can be determined.

In an exemplary embodiment of the invention, arm 102 (e.g., its locking and/or force application and/or movement) is controlled by a controller 114, for example a personal computer or a dedicated embedded computer. Optionally, a display 116 and/or a user input device 118 are used for interaction with a user. Optionally, display 116 comprises an audio display, for example for providing audible and/or speech instruction and/or feedback.

An external connection 120 for connection to a remote computer, is optionally provided, for example as described in Fig. 2 below.

It should be noted that some implementations of device 100 include no computer. Some implementations require no electrical power. In one example, a mechanical computer is used to control the device parameters.

#### Arm Specification

As will be described below in greater detail, various rehabilitation methods in accordance with exemplary embodiments of the invention require different types of motion and/or responsiveness from arm 102. In some embodiments of the invention the use of device 100 for rehabilitation places certain constraints on device 100, with respect to smoothness of motion.

For example, some types of rehabilitation in accordance with exemplary embodiments of the invention require a patient to move tip 108 along a trajectory. Resistance may be predefined along the trajectory or possibly no resistance at all. In any case, it may be desirable that device 100 not adversely affect motions by the patient, at least if they are correct. In a particular example, neutral directed motion, tip 108 provides no resistance to motion along a certain trajectory and strongly resists motion not along the certain trajectory.

In order to support generalized 3D trajectories in such a neutral manner, arm 102 is required to not have singularity points in a predefined and useful range of motion, for example a sphere of radius of 0.8 meters or less, for example, 0.5 meters or less. The term "singularity" is used to define a point and arm position where moving to a adjacent point passes the limits of

one or more joints and requires a relatively large change in joints position, which is generally time consuming and is exhibited to a patient as a sudden resistance or delay. In addition, providing neutral motion means that a uniform (and desirably zero) resistance can be provided at any point in the range of motion. Possibly more important is that any changes in resistance  
5 be smoothly varying. In some embodiments, arm 102 provides a counter-force or even motion. Uniformity and controllability of such force is required in some embodiments.

The magnitude of force that arm 102 can apply and/or resist depend on the rehabilitation methods used. For example, one rehabilitation type will require arm 102 to resist absolutely an incorrect motion, up to a force of 100 Kg applied at tip 108. In another example,  
10 it is sufficient that arm 102 resist motion up to a force level at which it is certain that the patient feels the resistance, for example, 1 Kg.

In an exemplary embodiment of the invention, the range of motion of tip 108 covers a volume of 50x50x50 cm. In other embodiments, a smaller or larger volume is provided. The volume need not be rectangular. Optionally, the volume also includes rotation of tip 108  
15 around one, two or three axes. In some embodiments, the volume is one or two dimensional.

In some embodiments of the invention arm 102 is expected to respond to a patient's activity in a manner which will seem natural or at least not interfere with the rehabilitation. In an exemplary embodiment of the invention, the responsiveness of arm 102 is better than 10 ms or better than 5 ms.

20 A general property of many mechanical systems is that due to manufacturing tolerances, sensing tolerances, design and/or non-optimality of the construction some uncontrollable freedom of motion is available. In an exemplary embodiment of the invention, the amount of unrestrained motion in device 100 is less than 5mm or less than 2 mm.

Robotic technology for achieving such ranges of motion and responsiveness and forces  
25 are well known. Optionally, controller 114 controls arm 102 in a passive, active or a responsive manner to achieve these objectives. In an exemplary embodiment of the invention, such active control of arm 102 results in compensation for at least 80% or more of the moment of inertia of arm 102. It should be noted that different values may be required for different situations, for example a greater or lesser responsiveness or a greater or lesser uncontrollable  
30 freedom.

Arm 102 is, for example, 1 meter, 0.8 meters, 0.5 meters, 0.3 meters or any greater smaller or intermediate length.

#### Motion types

In device 100 as illustrated, the motion which is controlled is of a single point, i.e., tip 108. By providing various attachments for tip 108, tip 108 may be connected, for example to a bone, to a joint or to a different part of the body. The attachment may be rigid, for example using a strap or it may depend on the patient, for example, as a handle or a rest. Specific attachment devices, for example for a hand, arm, elbow and/or shoulder may be provided. Further, as described below, multiple tips 108 (optionally with individual arms 102) may be provided for attachment at different points of the body.

When providing rehabilitation various types of motion may be supported, for example, one or more of:

- 10 a) Passive motion. Tip 108 is moved and the patient moves with it.
- b) Resisted motion. The patient moves tip 108 and encounters resistance. The resistance may be of various magnitudes.
- c) Assisted motion. When a patient moves tip 108, a positive feedback on arm 102 increases the force of motion in the direction moved by the patient.
- 15 d) Force field motion. The patient moves tip 108. Along a certain trajectory one level of resistance (or none) is encountered. Deviation from the trajectory is not allowed or meets with resistance. Fig. 3 shows an example of such a force field. Motion along a "correct" trajectory 302 can be without resistance, or possibly assisted. An increased resistance is exhibited in a volume 304 surrounding trajectory 302. An even greater resistance is exhibited in a surrounding volume 306. A prevention of motion may be provided in an outside volume 308. In an exemplary embodiment of the invention, a corrective force vector 310 is applied when not on trajectory 302, pointing towards trajectory 302. Optionally, instead of a corrective force, resistance varies as a function of distance from trajectory 302, thus, motion of tip 108 is naturally urged back to trajectory 302.
- 20 e) Mirrored motion. motion of tip 108 is required to mirror the trajectory of motion of a different element, for example for dual limb rehabilitation as described below.
- f) Free motion. Patient moves tip 108 in any way he desires, possibly receiving feedback.
- g) General Force Field. A force field and/or an assistance field is defined which is not related to any particular trajectory. For example, a range of trajectories may be allowed, or a real or virtual situation simulated.
- 30 h) Local force field. A force field which is applied to only a small locality and/or only in one or two dimensions.

i) Restricted motion. one or more points of the body are supported or prevented from moving. Optionally, the angles between such points and the moving points are measured.

Thus, in some embodiments of the invention, rehabilitation device 100 can provide one or more of Isokinetic, Isotonic and Isostatic exercises

5 It should be appreciated that a trajectory which tip 108 is to follow can include speed parameters. For example, a user may be assisted, or urged, or expected, to move tip 108 at a certain speed. The speed may be, for example, absolute, or relative (e.g., requiring a uniform speed or the speed to match a non-uniform profile).

10 Optionally, an angular trajectory is defined, which places constraints on an angular orientation of tip 108. In some embodiments, the constraint is one dimensional. In others it is two or three dimensional.

Speed, angles and spatial trajectories may each belong to a different one of the above motion types, in a particular rehabilitation scenario. For example, spatial trajectory may be of a force field type, while speed trajectory is free or assisted. The type of trajectory and/or its  
15 parameters may also vary along the trajectory, as a function of time and/or as a function of previous performance. For example, a smaller assistance at a later part of a trajectory may be provided for a type of motion which was properly (or better than expected) executed in an earlier part of the trajectory.

Trajectories may be absolute, for example, defined as a function of a resting point or a  
20 different point on device 100. In other embodiments, the trajectories are purely relative, for example, requiring a patient to move an arm in a straight line, regardless of starting point. In other embodiments, a trajectory is partially relative, in that once motion starts, this determines the shape of the rest of the trajectory, for example, a start of a trajectory indicating if a patient is standing or sitting, and thus what type of hand motion is expected..

25 In some embodiments, such as described below, where multiple points 108 are defined, the trajectories of each point may be of different types. In some embodiments, what is defined is a trajectory as a function of two or more points. For example, if two points are used to define an elbow configuration (e.g., angle between bones), the trajectory constraints may be defined on the motion of the elbow. Such motion may be relative in space (e.g., a comparison  
30 of the two points) and not absolute (e.g., compared to a device reference point).

It should be noted that in some embodiments of the invention a tensor or tensor field is provided, as each point in space can have associated with it a speed, a force and/or a rotation, all of which can be scalar or vectoric.

**Exemplary Usage**

Fig. 4A is a flowchart 400 of a method of using device 100, in accordance with an exemplary embodiment of the invention.

At 402, device 100 is powered on (for electrical devices). Optionally, device 100 turns on when arm 102 is touched or moved a certain amount. Alternatively, motion of arm 102 may provide power for device 100.

At 404, if a remote connection 120 is used, device 100 optionally downloads instructions, for example what activities to suggest and/or what progress was expected and/or results from physical therapy at other locations. Optionally, a patient identifies himself to device 100, for example, using a code, selecting a name from a list or using a smart card or a magnetic card with user input 118. Optionally, rehabilitation information of a patient is stored or indexed on such a magnetic card or smart card or on a portable flash memory device or portable hard disk.

At 406, an activity to be performed is selected. In a more automated device, the selection may be, for example automatic or by a patient from a displayed list of options. In a less automated device, for example, a patient may follow a chart provided to him by a rehabilitation center.

At 408, arm 102 is optionally moved to a start position thereof, for example by device 100 or by the patient (e.g., directly or by permitting device 100 to do so). It should be noted that in some trajectories no start position is predefined. Instead, the actual starting position is used to define the rest of the trajectory.

In some cases, device 100 is otherwise adjusted. For example, a particular handle may be attached at tip 108, or legs of the device may be raised or lowered. In a collapsible device (e.g., folding legs), the device may be set up. Optionally, such setting up is carried out before turning on the device.

At 410, an optional warm-up session is carried out on the patient, to ensure that he is ready for the activity. Optionally, one or more physiological sensors, for example a muscle temperature sensor (e.g., skin surface) are used to ensure (e.g., as a safety feature) that the patient is sufficiently warmed up.

At 412, the patient is optionally tested to confirm an expected current ability thereof.

At 414, the results of the test are optionally used to modify one or more parameters of the selected activity or to select a different activity, for example, due to an under- or over-achievement of the patient during testing. Exemplary modifications include: slowing down



expected speed, reducing expected or resistive force, reducing expected or allowed range of motion and reducing number of repetitions.

At 416, the activity is carried out, for example, continuous passive motion at 20 repetitions or motion (by patient) with resistance of 1 Kg, along the entire trajectory. In another  
 5 example, the resistance grows as a function of speed, or if the speed is higher or lower than a defined speed trajectory.

At 418, various measurements which are optionally made during the activity, are optionally logged. Such logging may also be carried out concurrently with the activity.

At 420, feedback may be provided based on the activity, for example, to the patient, a  
 10 rehabilitation expert and/or to device 100. Optionally, feedback is provided on a patient physiological condition as well, for example, determining fatigue based on increased irregularities of motion and/or based on pulse rate or other physiological parameters.

At 422, a decision is optionally made to repeat an activity and/or to select a new activity. Such a decision may be made, for example, based on patient progress and/or fatigue.

#### 15 Planning and Long-Term Progress

Fig. 4B is a flowchart 430 of a long term use of device 100, in accordance with an exemplary embodiment of the invention.

At 432, a new patient who is identified as needing rehabilitation is tested, possibly using device 100. For example, such tests may include, range of motion tests, tests of  
 20 maximum applied force at different points in space, and/or tests of fineness of force control and motion control. In an exemplary embodiment of the invention, device 100 calculates limb size (or detects them using a camera) and uses the limb size to adjust pre-stored exercises, for example their trajectories and/or starting point.

At 434, the results of the tests are analyzed to determine the needs of the patient and to  
 25 formulate objectives of the rehabilitation.

At 436, a rehabilitation plan is drawn up, including, for example one or more of an expected progress chart, various allowed and/or required exercises and exercise parameters for different parts of the plan, definitions of increased and decreased difficulty levels for the exercises, allowed and/or required exercise sequences, number of cycles for each exercise,  
 30 warm-up requirement, list of data to log, list of patient-modifiable information, one or more safety parameters which should not be passed and/or one or more parameter alert values at which an alert should be provided to the patient and/or a rehabilitation expert monitoring the patient's progress. It should be noted that while generating a rehabilitation plan is a known

activity, in an exemplary embodiment of the invention, such a plan is special, for example, taking into account one or more of the possibility of long term rehabilitation, the possibilities involved in having a device available at a home for multiple short sessions, the provision of multiple activities with a single device, the needs of remote monitors and/or the programmability and responsiveness of a device in accordance with some embodiments of the invention.

At 438, the plan is carried out, while being monitored. In an exemplary embodiment of the invention, the monitoring is manual. Alternatively, at least some of the monitoring is automatic.

At 440, the plan may be modified in response to the monitoring, for example, if slow progress is detected, the plan time frame may be changed.

In some cases, as rehabilitation progresses, new problems may come up or become emphasized. In some cases, the plan may be modified (440). In others, testing may be repeated (442), generally to a lesser extent than when the patient was initially evaluated.

In some plans, periodic testing (for example on device 100 at the patient's home) is part of the plan. Such evaluative testing may also be used to determine when rehabilitation is complete.

At 444, rehabilitation is mostly completed and a training plan is optionally made, for example to ensure maintenance of the rehabilitation or for other reasons (such as prevention of worsening or prevention of limb or joint neglecting).

At 446, long term monitoring of the patient may be performed, for example, testing the patient's abilities once a week or once a month.

At 448, new needs of the patient may be identified, for example based on the monitoring or based on a periodic general test. In one example, a patient being rehabilitated for stroke may be determined after a time to need rehabilitation for a progressing arthritis condition.

#### Home Use

In an exemplary embodiment of the invention, device 100 is adapted for home use. such adaptation may include one or more of the following features:

a) Small size. For example, device 100 may take up less than 1 meter squared of floor space. Optionally, device 100 is sized to fit through standard door ways (e.g., of width of 60 cm, 70 cm or 80 cm).

b) Simple interface. In an exemplary embodiment of the invention, device 100 has a

simple interface to a user, for example including a small number of options to choose from, graphical and/or speech instructions of use and feedback designed to be understood by a typical adult. In an exemplary embodiment of the invention, a wired or wireless pendant or wrist-worn controller is used. For example, such a controller can have a limited set of commands, including, an exercise selector dial, a button for selecting a dry-run or a slow version of the exercise, an activation button to start or stop an exercise, a scale or a pair of buttons to increase or decrease exercise difficulty level, and a LED or LCD display for feedback (e.g., red LED for bad and green LED for good). In an alternative embodiment, device 100 is voice activated and controlled, for example using an IVR (interactive voice response) type menu system.

c) Flexibility. In an exemplary embodiment of the invention, device 100 is designed to be used by a range of different sized patients and for a range of different treatments, for a plurality of different body parts and/or appendages, for example, 1, 2, 3 or four limbs or body parts or more. In some cases, various attachments may be provided. Optionally, device 100 is adapted for positioning at various orientations and/or in proximity to home activities, such as at a table for rehabilitation of feeding.

d) Lack of fixation. In some embodiments of the invention, device 100 is either simply fixed to a surface or not fixed at all, simplifying installation and de-installation.

In an exemplary embodiment of the invention, use is made of the fact that device 100. In one example, rehabilitation activities are designed to cover a larger part of the day than possible at an institute, for example, half or all of a day while still allowing a patient to have a life with non-rehabilitation activities. For example, a rehabilitation plan can call for 10 5 minute sessions spread over an entire day, one an hour.

In another example, device 100 interacts with real-life activities and/or using real-life objects, as described in more detail below. In particular, this allows a rehabilitation plan to show (and achieve) a patient a real progress in the patient's ability to deal with real life situations, such as eating and getting dressed.

#### Remote Use

As noted above, device 100 is optionally used as part of a distributed system. Fig. 2 shows an exemplary distributed rehabilitation system 200.

One or more homes with rehabilitation devices 100 are shown. A network 202, for example an Internet, a cable network, a cellular network or a telephone network, connects device 100 to a remote site. In an exemplary embodiment of the invention, a remote site is a

rehabilitation center including a computer station 204 with a display 206 and a user input 208. A single station 204 can monitor multiple devices 100, optionally in real time. A plurality of stations 204 may be provided, at a same or different sites. Optionally, a plurality of stations 204 are used to monitor a single device 100. For example, each device 100 may have a low  
5 level monitoring by a semi-skilled person, who shows difficult problems to a skilled monitor who is in charge of or associated with many unskilled monitored.

Also shown is an optional portable connection 212, for example using a lap top.

Also shown is an optional remote database 210, which may store data for one or more patients, for example, 100 or 1000 patients or more. While the database may be at the  
10 rehabilitation site, this is not required. In some cases the database is distributed, for example, among rehabilitation sites and/or user devices 100.

Other types of users may be supported as well as monitors, for example, a patient's general practitioner doctor may be able to log on and review a patient progress.

Remote rehabilitation can follow several paths, for example, one or more of:

15 a) Real-time monitoring. Optionally, a camera 214 is provided adjacent device 100 to allow a therapist to detect problems and/or give advice to a patient. Optionally, the data is analyzed by the therapist in real time. Alternatively, off-line analysis is provided. different pay schedules may be provided for different types of monitoring. In addition, different rehabilitation needs may indicate the level of interaction between a remote therapist and a  
20 patient. Optionally, camera 214 is controllable by the therapist, for example to zoom and/or pan to certain parts of the patient. Optionally, the path of the camera is pre-planned to track planned or actual motion by the patient and/or of various points on a body of the patient. Alternatively or additionally to camera 214, real-time monitoring may be provided by various position and orientation sensors associated with device 100. This may also require only a  
25 reduced bandwidth.

In an exemplary embodiment of the invention, a therapist can provide real-time feedback, for example using audio-visual methods and/or by commanding device 100 to respond in a certain way, for example, to increase force, to change a trajectory or to prevent a patient going past a safety limit.

30 b) Live start. A rehabilitation session is started live (e.g., on camera) and once the therapist is convinced the patient can work on his own, monitoring is stopped. Optionally, a patient can request help, for example during an activity or between activities.

c) Planning. Plans including exercises and/or programming for device 100 are provided

by the remote site, for example, weekly, or at the start of each session. In some embodiments, planning is automatic and optionally performed with or without patient input at device 100.

5 d) Monitoring. A remote site can specialize in analyzing data uploaded to it from device 100 or another location and suggest changes. Other types of monitoring can also be practiced, for example, checking to see how regularly a patient uses the system and/or for following complaints. A rehabilitation center may performed, for example, weekly checkups and possibly require periodic testing. Optionally, a patient may be called to come to the rehabilitation center, for example, for testing, teaching and/or additional therapy.

10 e) Testing. In an exemplary embodiment of the invention, a remote site uses device 100 to administer tests to a patient and assess his condition and/or progress. In an exemplary embodiment of the invention, such testing is used to assess the efficacy of drugs and/or other treatment prescribed for the patient. Optionally, periodic testing is used to select a most useful drug, for example, for a patient with Parkinson's disease or for a spastic patient.

15 f) Home therapist. In some embodiments of the invention, a therapist will come to the patients home for a rehabilitation session. For example, the therapist can set up device 100, mark correct starting positions, calibrate device 100 for the particular patient (e.g., size) and/or teach the patient the use of device 100. Optionally, the therapist can access and/or be in contact with a remote site, for example, for advice and/or monitoring of his work. When a therapist comes for later sessions, the remote site may assist with comparing current and past  
20 performance, for example.

g) Remote maintenance. In an exemplary embodiment of the invention, device 100 can be maintained from a remote location, for example, including one or more of reporting by device 100 of technical problems; remote testing of mechanical abilities of device 100, with or without patient assistance; remote testing of sensing abilities of device 100, with or without  
25 patient assistance; downloading and uploading logs; and/or downloading and uploading software. Optionally, device 100 collects billing information which is remotely accessed. Optionally, device 100 collects usage information which may be used, for example, by an insurance company. In some embodiments, remote access to device 100 is designed to maintain patient privacy, for example by hiding patient identifying information, by limiting  
30 access to various logs and records and/or using password and other authentication schemes.

In an exemplary embodiment of the invention, virtual reality methods, for example goggle mounted displays are provided at the remote location, to help the remote operator feel in better control. Alternatively or additionally, the operator can manipulate his viewpoint. In an



exemplary embodiment of the invention, various sensors (for example as described below) are used to move a model of the patient, for remote and/or local feedback.

#### Feedback

Various types of feedback are envisioned for use with exemplary embodiments of the invention, for example, one or more of:

a) Feedback from a patient. Optionally, a patient can provide feedback to a therapist, for example, using voice annotations or text annotations. In one example, such feedback is provided during an activity. In another example, a patient reviews a recording of the activity and then adds comments. In some activities supported by exemplary embodiments of the invention, a patient is requested to manipulate a control, when a certain situation is reached, for example, a maximum force. Feedback may also be provided by the patient for a plan or progress, not only for individual activities.

In some embodiments of the invention, patient feedback is processed by device 100 to modify and/or decide on current or future activities and/or their parameters. For example, if a patient marks that a certain force is a maximum force, later activities will not pass that force. In some embodiments of the invention, no explicit user feedback is required, instead, the system can implicitly determine when a maximum force is approached, for example based on difficulty in control, and model future activities on the thus determined force.

b) Feedback to patient. In an exemplary embodiment of the invention, feedback is presented to a patient, for example, during an activity, in rest breaks and/or after an activity. For example, such feedback can include an indication to the user that he is performing an activity incorrectly, that future cycles should be done differently and/or a comparison between current and past performance and/or other statistics. It should be noted that in many cases positive feedback is as important or even more important than negative feedback. This may depend on the rehabilitation method used.

Various feedback modalities may be provided, for example, speech and audio feedback, a display containing text or graphics, a marked up video image, force or vibration feedback on device 100 (e.g., by tip 108), using a separate element (such as the above pendant) and/or using virtual reality devices, such as goggle mounted displays, in which the type, position and/or other parameters of a mistake (or correct action) are shown overlaid on a real or virtual image of the activity.

c) Feedback to therapist. In an exemplary embodiment of the invention, a local or remote therapist is provided with feedback. Such feedback can include, for example, one or

more of force levels, an indication of mistakes, a notification of missing, exceeding or meeting certain parameters, a predefined alert, a motion quality (described below) a safety situation and/or a statistical analysis of a current and/or a past activity.

d) Feedback from remote therapist. In an exemplary embodiment of the invention, feedback is provided by a remote therapist, for example as indicated above of feedback that a patient may receive. Optionally, such feedback includes instruction to device 100 if to repeat a certain exercise and/or modify parameters. In an exemplary embodiment of the invention, an exercise is defined with, or a therapist can add, break points, at which the therapist, patient and/or device 100 (depending for example on implementation) can decide, for example, if to modify future parameters, impose a rest and/or repeat an activity if a desired result was not achieved. Such a breakpoint need not be notice by a patient, if no decision is made by him and a decision is made fast enough or during a short, pre-defined, break.

e) Feedback from device 100. Depending on the automation level of device 100, feedback can be provided by the device, for example indicating a threshold was past or indicating a safety problem.

#### Programming

In an exemplary embodiment of the invention, various aspects of a rehabilitation process can be planned and inputted as instructions to a computer (e.g., device 100), including, one or more of:

- a) designing a new exercise;
- b) modifying an exercise for a particular situation and/or patient;
- c) designing and modifying a rehabilitation plan; and
- d) designing and modifying decision logic (e.g., breakpoints, thresholds and repetitions).

Permissions may be different for different users of system 200 and/or device 100, for example, different permissions may be allowed for one or more of adding new, copy, modify, delete and/or edit. These activities may apply, for example, to one or more of patient data, activity, plan, statistics and/or data logs. Particular activity parameters which may be created and/or modified in accordance with exemplary embodiments of the invention include: trajectories and ranges (e.g., minimum and maximum speed and angles); force parameters, number of repetition cycles, stop decision(s) and/or rest periods length and frequency.

In some embodiments of the invention, one or more libraries are provided as a basis for modification and for storing programs, for example, a plan library, a per-patient library and/or

an activity library.

In an exemplary embodiment of the invention, entering a new trajectory is by physically manipulating tip 108 (e.g., by a patient with a good hand or by a therapist). Optionally, the resulting trajectory(s) are then edited on a computer. Alternatively or  
 5 additionally, a 3D CAD/CAM program may be used, optionally one in which a human body is modeled and various constraints can be placed on movement of points on the body and/or a desired or allowed range of motion for such points defined. Optionally, a graphic design program is used, for example, with a user indicating a few points of a trajectory and the program completing them with a line or a curve. Alternatively or additionally, a user may  
 10 define various geometrical shapes, such as a circle, for example by providing points and/or a formula. Alternatively or additionally, a user may make a drawing and scan it into system 200 (e.g., at a station 204 or at device 100).

In an exemplary embodiment of the invention, an exercise is calibrated for a particular patient and/or situation. Such calibration may include, for example, one or more of:

- 15 a) calibration to patient abilities, such as angular range of motion of a joint or ability to apply force or maintaining fine positional control;
- b) calibration to a size of a patient, for example, the length of a limb or a bone;
- c) calibration to progress, for example, a plan may have its time span and/or its step size changed based on exhibited or expected progress.

#### 20 Sensing of Limb Position

In device 100, as illustrated, only one point of the patient is controlled, the point in contact with tip 108. However, this means that multiple different arm motions can result in a same spatial trajectory. For some situations this is not a problem. For example, for recovery from stroke, in some cases, any motion is useful. In other rehabilitation scenarios, it is  
 25 desirable to better dictate or know the positions of all the moving body parts. In some exemplary embodiments of the invention, the position of other body parts is fixed. For example, a patient may be strapped to a chair (e.g., the shoulder of the patient) and/or a rest may be provided for an elbow. This restricts possible motions by a hand holding tip 108.

Fig. 5 illustrates a system 500 including limb position sensing and/or restricting, in  
 30 accordance with an exemplary embodiment of the invention. Correct motion of other parts of the body than the hand that contacts tip 108 may be provided, for example, by detecting the positions and providing feedback, for example, audio or visual feedback, to the patient.

A patient 506 sits in a chair 514 and uses device 100 (or a device as described below in

which the arm is mounted on a ball). One or more cameras 502 image the arm and/or other parts of patient 506 and determine the spatial position and/or velocity thereof. Alternatively or additionally, one or more cameras 516 are mounted on device 100 for such imaging. In some implementation of image based reconstruction of body positions, it is useful to include one or  
 5 more fiduciary markers 504, for example strap-on patterns or LEDs.

Alternatively to image based position sensing, magnetic, electric, ultrasonic or other contact-less position sensing and orientation sensing methods may be used. Many such position determination methods and devices are known in the art and may be used. In an exemplary embodiment of the invention, a reference position is provided on device 100 and/or  
 10 on tip 108. Optionally, such position sensors are used for determining the state of device 100, instead of or in addition to mechanical sensors in device 100.

Alternatively or additionally to using contact-less position sensing, mechanical based position sensing, for example using an articulated arm, may be used.

It should be appreciated that in some embodiments of the invention no arm 102 is  
 15 provided, instead position sensors of some type are used. Feedback is optionally provided via virtual reality type displays and feedback (e.g., vibration to emulate force). However, this may not allow direct force feedback and resistance to be applied, as desired in other exemplary embodiments of the invention.

In an exemplary embodiment of the invention, sensed positions of body points are used  
 20 for one or more of:

- a) determining if a body motion is correct;
- b) determining what motions are possible (e.g., based on angles of joints);
- c) learning desired motions from an example; and/or
- d) monitoring a patient's ability (e.g., for testing or limb measurements).

25 Alternatively or additionally to position, orientation and velocity sensors, physiological sensors may be provided, for example, pulse measurement sensors as known in exercise machines and grip force sensors in tip 108. Alternatively or additionally, one or more physiological sensors may be provided on the patient, for example, breath rate sensors.

Referring back to Fig. 5, alternatively or additionally to position sensors, a body rest  
 30 508 may be provided for one or more body parts. In the example shown, rest 508, attached to chair 514 by a (optionally adjustable) bar 510 prevents motion of the chest and/or shoulder. In an alternative embodiment, one or more straps are used to hold body parts.

Optionally, chair 514 is fixed to device 100, possibly in an adjustable manner, for

example, using a fixation bar 512. Optionally, an initial calibration process is carried out, for example when first doing a new activity or during device setup. In one example, bar 512 includes graduations and during calibrations the correct setting of the chair relative to the graduations is determined.

5 In some embodiments of the invention, device 100 comes with a built-in chair 514.

#### Attachment

In Fig. 1, tip 108 is held in a patient's hand. To attach to other parts of the body, other means may be used. In one example, a strap or elastic ring is provided at end 108 instead of a ball-like handle. In another example, a rod-like handle is provided instead of a ball-like handle.

10 Fig. 6 shows an elbow holder 600, in accordance with an exemplary embodiment of the invention. Such an elbow holder can be used, for example, when the motion required is of the shoulder, so an elbow 616 is what moves along a trajectory. A base 602 is adapted for attachment at tip 108. A hinge 604 allows relative motion between a first part 606 and a second part 608 on which an arm 614 rests. Optional straps 610 and 612 optionally attach arm  
15 614 more firmly to holder 610. Optionally, joint 604 has a varying resistance, for example settable by the patient and/or by device 100. Alternatively or additionally, joint 604 includes an actuator for applying force to close or open elbow 616. Alternatively or additionally, joint 604 includes an angle sensor.

In an exemplary embodiment of the invention, holder 600 functions as a spastic harness  
20 in one example, joint 604 is locked (or is not a joint) and arm 614 is forced open and held by straps 610 and 612.

In an exemplary embodiment of the invention, parts 608 and 606 are raised so that joint 604 has a center of rotation which is substantially the same as elbow 616, in one or more planes.

25 In other embodiments of the invention, attachment to other points on the body is provided. In particular, it is noted that in some embodiments of the invention, what is constrained is a joint, while in other, what is constrained is a bone or a certain location on a bone. As noted above, various types of constraints can be provided, for example, constraints on angular and/or spatial dimensions.

30 In an exemplary embodiment of the invention, the attachment includes a coded circuit or other means so that when attached to arm 102, device 100 is aware of the type of attachment.

#### Training and Teaching



While one part of a rehabilitation plan is often exercising a body part to maintaining or increase strength or range of motion, in an exemplary embodiment of the invention, rehabilitation includes teaching a patient quality aspects of motions and/or what motions are correct.

5 In an exemplary embodiment of the invention, one or more of the following qualities of a motion are of interest:

- a) degree of utilization of available joints and/or joint range of motion;
- b) usage of muscles where they can apply sufficient force;
- c) motion where joints and/or muscles can achieve a better accuracy of control;
- 10 d) motion which does not approach thresholds of ability;
- e) motion which does not approach danger areas (for example for a patient with unstable joints);
- f) smoothness in motion and/or rotation;
- g) distance traveled;
- 15 h) maximum force required; and/or
- i) spatial and/or energy efficiency of motion, e.g., extra motions.

These qualities may be general for a motion or particular for a patient with certain abilities and lacks.

20 In an exemplary embodiment of the invention, such qualities of a motion are taught to a patient by example, for example, leading an arm through better and worse motions. Such motions may be entered for example by the therapist or by the patient or be pre-programmed. Alternatively or additionally, a patient motion is recorded and corrected and then the patient is paced through the incorrect and the corrected motions. In a pre-defined motion, the motion may be calibrated for the particular user, for example for the user's size.

25 Optionally, a threshold of correctness is defined, for a patient to attempt to keep all his motions as being of a quality (in one or more parameters) above the threshold.

Alternatively or additionally, such qualities are taught by a commenting in real-time or off-line on a patient's motions.

30 Thus, in some embodiments of the invention, a substantial part of rehabilitation comprises exercising a patient in motions which are correct or teaching the patient how to know if a certain motion he has performed is of a higher or of a lower quality.

Other types of training are not related to motion correctness. For example, a patient may be trained to not ignore a damaged limb. In a related aspect, however, a patient may be

trained to use a damaged joint as part of "correct" motion, so as not to reduce a range of motion of the joint.

### Paired Motion

In an exemplary embodiment of the invention, motion with a good arm limb is used to train a bad limb. For example, a good arm can be used to trace a circle and then the bad arm is trained to trace the circle. One advantage of such training is the intimate feedback that a patient receives by better understanding exactly which joints and muscles are used for each motion. In an alternative application, the "good" motion is provided by a therapist.

In a single arm device 100, the following process may be used:

- 10 a) Device 100 optionally illustrates a correct motion, in actuality or on a display.
- b) A motion is executed with a "good" limb. Optionally, the motion is corrected, using methods as described above for editing.
- c) The motion is repeated with a "bad" limb, for example using passive motion, free motion or a force field. Optionally, the "good" motion is corrected before being applied to the
- 15 bad limb, for example, an expected speed reduced, a range of motion reduced or a force reduced.
- d) Feedback is provided to the patient during and/or after the motion (e.g., as a display).
- e) The motion is optionally repeated.

20 Fig. 7 and Fig. 8 shows two handle devices 700 and 800 respectively, in which two arms can be moved simultaneously, with optional coupling. In an exemplary embodiment of the invention, this is used to have one arm passively move the other arm, for example so the patient can sense with the good arm what a bad arm is doing, or vice versa. Alternatively or additionally, one handle is moved by the device, so the patient can see what is expected of

25 him.

In device 700, two separate rehabilitation devices 702 and 704 are optionally attached by a base 706 and coupled by computer, electrically and/or mechanically, so that an arm 708 of one mimics the motion of an arm 710 of the other. The arm moving mechanism is optionally a ball based mechanism as described below.

30 In device 800, a single joint links two arms 808 and 810. As a result, the motions are reversed. Optionally, arms 808 and 810 are extendible (as described below, for example) and are linked together so that they both lengthen and shorten together, for example, the two arms including extensions that are engaged on opposite sides of a gear with a fixed center of rotation

(e.g., a rack and pinion mechanism).

In an exemplary embodiment of the invention, mirrored motion is provided using other devices. For example, in an application using standard devices, mirrored motion is provided by a user holding one mouse in either hand (or in a same hand sequentially) and applying the  
 5 above transfer of motion from one hand to the other. In another embodiment, one or two force-feedback joysticks are used. It should be noted that for this and other embodiments a plurality of devices may be used. In particular, for specific applications, relatively simple and/or standard hardware can be used, for example force feedback joysticks or haptic displays.

### Complex Motion

10 Fig. 9A illustrates a rehabilitation device 900 comprising two sections, a first section 902 associated with motion of a wrist and a second section 904 associated with motion of an elbow. Sections 902 and 904 can be ball-based devices as described below. A rigid and optionally adjustable connection 910 fixes the relative position of sections 902 and 904. A connection 912 optionally interconnects a wrist holder 906 and an elbow holder 908.

15 In use, each of holders 908 and 906 can be controlled in three spatial dimensions and optionally in angular dimensions as well, thus allowing more complex motions to be tested, trained and/or provided. Optionally, the possibility of restricting certain motions is useful from a safety point of view, for example, preventing certain rotations of the joints.

It should be noted that in device 900, trajectories may be defined, for some uses as  
 20 relative trajectories in which the actual position of the device 900 is less important than the relative positions and movement in space of holders 906 and 908.

Fig. 9B illustrates a rehabilitation device 920, including a single section 928 with an arm 932, on which is mounted an arm holder 930. Holder 930 restrains both an elbow using an elbow holder 924 and a wrist, using a wrist holder 922. A rotation mechanism 926 is shown  
 25 for rotating holder 930 around arm 932. Alternatively or additionally, a similar mechanism (not shown) is optionally provided for rotating holder 930 around its axis.

As will be described below, another type of complex motion which can be supported by a rehabilitation device in accordance with an exemplary embodiments of the invention requires synchronized motion of several body parts, for example, an arm and a leg.

### 30. Ball-Based Device

As noted above, designs other than an articulated arm may be used for device 100. In particular, in an exemplary embodiment of the invention, the device is based on a universal joint, for which extends a rigid arm, which is optionally extendible.

In an exemplary embodiment of the invention, the universal joint is implemented as a ball in socket joint. Fig. 10 shows an exemplary rehabilitation device 1000, using a ball-in-socket joint.

Device 100 comprises a base 1004, for example a table containing a plate 1016, with  
5 an aperture 1017 defined therein and enclosing a ball 1010. Ball 1010 optionally rests on a plurality of rollers 1012. In an alternative embodiment shown in Fig. 11, rollers 1012 are replaced by a bottom plate 1015 with an aperture 1013 defined therein which supports ball 1010.

An arm 1002 extends from ball 1010 and is optionally balanced by a counter-weight  
10 1018 attached by a rod 1022 to an opposite side of ball 1010. Rod 1022 optionally passes through a slot in an optional guide plate 1020, described in greater detail below.

In use, ball 1010 turns and/or rotates, allowing a tip 1008 of arm 1002 to define various trajectories in space. Optionally, arm 1002 is extendible, so that the trajectories fill a volume of space. Optionally, arm 1002 includes a motor or brake 1024 (e.g., an oil brake), to actively  
15 move or passively resist such extension.

In an exemplary embodiment of the invention, a brake 1014 is provided for ball 1010. One potential benefit of using a relatively large ball 1010 is that torque at the surface of the ball, for example as required for braking or moving arm 1002 is generally smaller than required for smaller joints, possibly allowing the use of smaller or cheaper motors or other  
20 mechanical elements. Alternatively or additionally, positional control of such motors and/or sensitivity of position sensors can be smaller, while still allowing for sufficiently precise control and feedback.

Device 1000 can be provided in various configurations. In a simplest configuration, the device is completely passive and a user can merely set plate settings (described below) and  
25 resistance settings on the brakes. In a more advanced configuration, resistance can be varied in real-time by a computer control. In another advanced configuration, sensing of ball and/or arm position is provided (e.g., using sensors, not shown). In another advanced configuration, directional resistance can be varied (e.g., using a directional brake, not shown). In another advanced configuration, motive force, optionally directional can be set or varied, for example  
30 using a plate and/or using multiple directional motors.

In an exemplary embodiment of the invention, multiple motors are used to control motion and/or force of arm 1002. The motors optionally include optical position encoders, to determine an arm position. Alternatively or additionally, stepper motors or servo motors are

used. Alternatively or additionally, a separate sensor, for example, one which reads optical markings off of ball 1010, is used. In an exemplary embodiment of the invention, rollers 1012 are replaced by motors which rotate wheels. If one wheel is in a direction (relative to the surface of ball 1010) perpendicular to another such wheel, selective motion in one or both  
 5 directions can be achieved (e.g., if motion perpendicular to the wheel is low-friction slipping motion). Alternatively, only one roller is replaced by a motor with a turning wheel, wherein the wheel is turned to a direction of motion desired and then rotated to achieve the motion. Directional resistance is optionally achieved using the motor. Alternatively, such resistance is achieved by a combination of the motor applying force or resistance and a general resistance  
 10 applied by brake 1014. Optionally, one or more strain sensors are provided or integrated in the motor(s), to assess a direction of force being applied to arm 1002. Then, the motors can respond with a counter-force, or an assisting force or a diverting force (e.g., with a component perpendicular to the applied force), as required.

In an exemplary embodiment of the invention, brake 1014 is operated by raising and  
 15 lowering the brake towards the equator of ball 1014, when the brake has an inner diameter of less than that of the ball. Alternatively, the brake is inflated and deflated as needed. Alternatively or additionally, a circumference of the brake is modified, for example, by it being formed of shape memory alloys which are heated to cause momentary expansion and/or shrinkage of the brake. Alternatively or additionally, a perpendicular brake is used which is  
 20 pressed onto the surface of ball 1010 and towards the center thereof.

Alternatively or additionally to a uni-directional brake, directional brakes may be used, for example, rubber blades-like pads which resist motion of the ball along the blade by bend with relatively low friction to allow motion perpendicular to the blade.

It should be noted that when arm 1002 is extendible, forces applied to point 1008  
 25 generally include also a component along the axis of arm 1002, to which brake or motor 1024 may respond and which is optionally taken into account in the response of ball 1010.

#### **Balance**

Fig. 11 shows a balancing of device 1000, in accordance with an exemplary embodiment of the invention. As noted above, Fig. 11 shows a variant of device 1000, in  
 30 which ball 1010 is supported by plate 1015. Weight 1018 is optionally designed to exactly cancel the moment of arm 1002. Alternatively, it may be designed, or modified (e.g., by changing its distance from ball 1010 or by adding or removing a modular weight), to provide a force which return arm 1002 to a resting position or a force which tends to move it away from



such a resting position.

Optionally, when arm 1002 is extendible, the extending part includes a moving counter-weight that extends away from the center of ball 1010 in a manner which maintains the center of gravity of ball 1010. This motion may be solely inside of ball 1010.

5 Alternatively or additionally, balancing of ball 1010 is provided by active balancing by the motors and/or brakes. Such active balancing may also be used to effectively reduce or cancel out the moment of inertia of ball 1010 and arm 1002.

When an attachment is added to tip 1008, this may change the balancing. Optionally, a suitable weight is provided with each such adjustment, for adding to balancing weight 1018.  
10 Alternatively, handle 1008 includes one or more contacts and/or circuitry which match one or more contacts or circuitry in a mating part of the attachment. This allows device 1000 to detect which attachment is being added and suitably move weight 1018 to compensate. Suitable tables are optionally downloaded from a remote site. Alternatively, the attachment includes a peg of suitable length which pushes into tip 1008 and thereby moves an arm balancing weight  
15 inside of ball 1010. Movement of weight 1018 is optionally by a motor (not shown) and may be, for example, along a rod 1022 and/or away from a line connecting rod 1022 and arm 1002. Alternatively or additionally, device 100 self calibrates by detecting an applied torque moment and moving weight 1018 (or other weights) to compensate.

Optionally, the balancing is designed relative to an expected weight or force applied by  
20 a person during an activity.

Fig. 11 also shows rod 1022 being constrained to travel in a straight line by a slot 1030 in plate 1020.

#### Guide Plate

While, in general, computer controlled directional motors and brakes can achieve any  
25 desired motion, in some embodiments of the invention, a possibly more limited motion is supported by the use of plate 102 and its associated slots 1030. A potential advantage of using guide plates is that movement perpendicular to the slot is not generally possible, and this does not require suitable circuitry.

Fig. 12 illustrates a drive system for a plate-based rehabilitation device, in accordance  
30 with an exemplary embodiment of the invention. A first, optional, motor 1046 is attached to a gear 1048 which rotates plate 1020 to allow motion of rod 1022 in other than a straight line. A second, optional motor 1040 is attached to a threaded rod 1042 on which a rod coupler 1044 travels. As coupler 1044 travels, it moves (or resists) rod 1022 along slot 1030. Other

mechanisms can be used as well.

As noted in Fig. 3, it is sometimes desirable to provide varying, rather than absolute resistance to motion perpendicular to slot 1030. Fig. 13A illustrates an exemplary coupling device 1300 for replacing coupler 1044, and which has this property. Coupling device 1300 includes a body 1314 having an inner threaded section 1302 for mounting on threaded rod 1042. Body 1314 further comprises an apertured element 1306 having an aperture 1304 which engages rod 1022. One or more spring elements 1308 couples element 1304 to body 1314. Optionally, the tension in spring element 1308 can be adjusted, for example by a screw 1310. Optionally, a linear displacement sensor 1312 is provided to measure the error in the position of rod 1022. Elements 1308 can be provided, for example, in the direction of slot 1030 and/or perpendicular to it.

Fig. 13B shows an elastic guide 1340, formed of two halves 1342 and 1344 coupled by one or more springs 1352 and 1354. Thus, a slot 1346 formed between two edges 1348 and 1350 of the halves has some elastic give. Alternatively or additionally, edges 1348 and 1350 are made at least partially elastic, for example, of rubber.

Figs. 14A illustrates a variant device, in which two guide plates are used in tandem, an upper guide plate 1020 and a lower guide plate 1402. Separate motors are optionally provided for rotating each guide plate.

Fig. 14B shows a guide plate with several slots.

Fig. 14C shows a guide plate with an "X" shaped slot. Other shapes can be provided as well, for example a circle with a cross inside, or curved slots.

In an exemplary embodiment of the invention, programming device 1000 includes replacing slots and/or setting resistance. Optionally, when a slot is inserted, it is recognized by device 1000, for example, using a contact based detection scheme as described above or using a wireless or RF communication, for example, by embedding a smart card circuitry in the plate.

#### Wrist Attachment

Fig. 15 shows a wrist attachment 1500, which provides control and/or feedback for one or more degrees of motion of a hand, in accordance with an exemplary embodiment of the invention.

A forearm is supposed to rest on a rest 1510, while a grip 1502 is grasped by the hand. Grip 1502 is gimbaled in one or more axes relative to rest 1510. In the example shown, handle 1502 is mounted on a base 1503 which includes a rod 1504. A joint section 1506 can

optionally rotate around the axis of rod 1504 and/or travel along it. In addition, an optional rod 1508 interconnects rest 1510 and joint section 1506 and allow rotation around rod 1508. In addition, an optional rod 1512 meets joint section 1506 at a direction perpendicular to the other two rods and allows rotation around that third axis.

5        Optionally, wrist attachment 1500 is attached to tip 1508 at rest 1510 or at a base section 1514 attached to rod 1508.

Optionally, one or more of the relative motions described is supported by one or more motors and/or controllable brakes.

10        In some wrist attachments (or for other attachment devices), one or more springs the handle to the rehabilitation device so as to provide the varying resistance shown in Fig. 3, in one or more dimensions.

#### Elbow Support

15        Figs. 16A-16D illustrate various methods of elbow support in accordance with exemplary embodiments of the invention. As noted above, for some rehabilitation methods it is useful to provide support for and/or prevent motion of the elbow (or other body parts).

Fig. 16A shows an elbow support 1604 attached by wires to a frame 1602, fixed to the rehabilitation device. Optionally, frame 1602 is collapsible.

Fig. 16B shows elbow support 1604 supported by an arm 1610 which extends from the rehabilitation device.

20        Fig. 16C shows elbow support 1604 supported by a jointed arm 1620 which extends from the rehabilitation device.

Fig. 16D shows elbow support 1604 supported by a member which extends out of (or is mounted on) arm 1002.

25        Optionally, the extending arms and members are configurable. Alternatively or additionally, the arms include motors and/or variable resistance elements. Alternatively or additionally, the arms include position, orientation, displacement and/or force sensors.

#### Non-Vertical Orientation

30        In some embodiments of the invention it is desirable that arm 102 have a center resting position which is not vertical. Fig. 17 shows a rehabilitation device 1700, including a joint 1702 between a base 1704 thereof and a movement mechanism 1706 thereof, which can assume multiple orientations.

Alternatively, one of the above described rehabilitation devices may be mounted on a surface other than the floor or on legs with uneven lengths. Optionally, when device 1000 is

mounted on a wall or upside down, rollers such as rollers 1012 are provided above ball 1010 as well, so that they can support ball 1010, when device 1000 is on its side or upside down. Mounting is achieved, for example, by screws or using an adhesive.

#### Multi-Limb Devices

5 In an exemplary embodiment of the invention, multiple limbs can be trained together, for example, for rehabilitating synchronized motion. In an exemplary embodiment of the invention, multiple modules such as used in device 1000 are attached in various configurations to achieve this effect. The attachment can be, for example, structural (e.g., preventing undesired relative motion, but possibly adjustable), mechanical, for example transmitting  
10 motion from one module to another, controlled, for example, modifying the interaction at one module in response or in synchrony with interaction at another module.

Fig. 18 shows a rehabilitation device 1800 for an arm and a leg, in accordance with an exemplary embodiment of the invention. Device 1800 includes a first section 1804 for exercising an arm, for example using a mechanism of device 1000, and a second section 1802  
15 for exercising a leg, for example also using the mechanism of device 1000.

One exemplary use for this type of device is to rehabilitate a stroke victim with one side paralysis. Another exemplary use is to train synchronized motions, such as required for walking.

In some cases, two sided rehabilitation is desirable. Fig. 19 shows a rehabilitation  
20 device 1900 with four mechanism modules. A pair of modules 1902 and 1904 is used to control the movements of a right arm and a pair of mechanism modules 1906 and 1908 is used to control the movements of a left arm. The two pairs of modules can be synchronized and/or used for teaching, for example, as described above.

Optionally, one or more modules are added for exercising each leg.

#### 25 Small Chuck

In an exemplary embodiment of the invention, a joint in an articulated arm is configured to provide selective and/or directional resistance.

Fig. 20 is a cross-sectional view of such a joint between a rod 2004 and a rod 2002. A  
30 chuck 2006 fits into a flaring end 2008 of rod 2004 and engages a ball 2012 attached to rod 2002. If chuck 2006 is retracted towards rod 2004, it tightens around ball 2012 and increases the resistance thereof.

Optionally, one or more strain sensors 2010 is provided between chuck 2006 and ball 2012, so that a direction of force being applied to joint 2000, can be determined. Optionally,

one or more electrically activated brake elements are provided, for example piezoelectric elements, which can selectively modify a degree of resistance. This may be provided instead of or additional to a retracting chuck mechanism.

#### **Balanced Gimbal Device**

5 Fig. 21 shows an alternative rehabilitation device 2100, in which a ball joint is not used. An arm 2102, optionally extendible is optionally balanced by an optional counter-weight 2110 around an axle 2106. Counter-weight 2110 may include a motor or variable brake for controlling extension of arm 2102.

10 A motor 2108 is optionally provided to rotate arm 2102 around axle 2106. A second hinge 2112 is provided to allow rotation around an axis perpendicular to arm 2102 and axle 2106. Optionally, motor 2108 includes a weight so that it balances arm 2102 relative to hinge 2112. Optionally a slot 2114 is provided in a base section 2104 of device 2100, for functioning as plate 1020 and slot 1030 above. A similar structural arrangement may be used as well. A motor (not shown) is optionally provided for rotation around joint 2112.

#### 15 **Safety**

In an exemplary embodiment of the invention, one or more safety features are provided to prevent injury to a patient. For example, one or more of the following safety mechanism may be used:

20 a) Dead man switch. If a patient releases this switch (or touches a suitable button) movement of device 100 is frozen and/or all forces and resistance brought to zero. Other "safe harbor" situations can be defined instead.

b) Tearing pin. A pin may be used to attach tip 1008 (or other attachment) to arm 1002. If a certain threshold force is exceeded, the pin tears and the attachment is released from the arm. Different pins with different tearing thresholds may be selected for different situations.

25 c) Locking. Arm 1002 may have an initial locking condition, to allow a patient to lean on it.

d) Voice activation. Voice activation and/or deactivation may be provided, to allow a patient to shout the system to a stop.

30 e) Analysis. Optionally, the actual movements and/or forces applied by a patient are analyzed to determine if a threshold is being approached or if the patient is experiencing undue stress.

#### **Daily Life**

As noted above, in an exemplary embodiment of the invention, a rehabilitation device



is used to help specifically rehabilitate a patient to achieve daily activities, such as opening doors, eating at a table, reading a book, getting dressed, brushing teeth and washing dishes.

Fig. 22 shows a rehabilitation device 2200 configured for use for daily activities, in accordance with an exemplary embodiment of the invention. A rehabilitation module 2202 is mounted upside down over a table 2206 set with various eating utensils. An elbow rest 2204 is optionally provided. In this embodiment table 2206 is attached to a frame 2210 which supports mechanism 2202. Alternatively, frame 2210 may be wide enough to surround an existing table or other home element.

In use, a hand of the patient is strapped to a movable tip 2208 of device 2200 and the user attempts to or is guided through a daily activity such as picking up a fork. Optionally, a glove with force-feedback is used to selectively rehabilitate individual fingers. Such gloves are known in the art.

In an exemplary embodiment of the invention, device 2200 is used for one or more of training a patient to do activities related to daily life, testing the patient's current ability to do such activities and/or monitoring a patient's ability. Optionally, such testing and/or monitoring is used by insurance companies to decide on compensation or assistance required. Such testing can be repeated over a period of time so that attempts to cheat may be detected by sudden spikes in ability.

It is noted that a very important goal for rehabilitation is quality of life, which is optionally addressed and/or determined by training and testing the ability to perform various daily activities.

It should be noted that the rehabilitation devices described herein are optional usable not only at a home but also at care centers, such as old age homes, hospitals and rehabilitation centers.

## 25 **Balance Training**

In an exemplary embodiment of the invention, a rehabilitation module is used for balance training. In one example, a seat is attached to tip 1008 and a patient sits on the seat. A non-rotating plate 1020 with a slot sets the direction in which the seat is allowed to roll and the resistance level sets the difficulty. Optionally, a handle bar is provided. Alternatively or additionally, a foot rest and/or pedals are provided for the feet. Alternatively one or more rehabilitation modules for the arms are provided. In this manner, various daily and sports activities can be simulated and trained for. Optionally, a virtual reality type display or a television display are provided to enhance the sense of reality. Such a virtual reality display

may be provided in other embodiments of the invention, for example to show feedback, to show instructions or to make the activity more interesting.

#### Other Devices

5 Various designs for robots and positioning devices (e.g., hexapods) are known in the art. It should be appreciated that various ones of the statements described herein may be adapted for such robots and/or positioning devices, in accordance with exemplary embodiments of the invention. Alternatively or additionally, software may be provided for such robots and devices for carrying out various of the methods described herein, all in accordance with exemplary embodiments of the invention.

10 It will be appreciated that the above described methods of rehabilitation may be varied in many ways, including, omitting or adding steps, changing the order of steps and the types of devices used. In addition, a multiplicity of various features, both of method and of devices have been described. In some embodiments mainly methods are described, however, also apparatus adapted for performing the methods are considered to be within the scope of the  
15 invention. It should be appreciated that different features may be combined in different ways. In particular, not all the features shown above in a particular embodiment are necessary in every similar embodiment of the invention. Further, combinations of the above features are also considered to be within the scope of some embodiments of the invention. Also within the scope of the invention are kits which include sets of a device, one or more tearing pins, one or  
20 more attachments and/or software. Also, within the scope is hardware, software and computer readable-media including such software which is used for carrying out and/or guiding the steps described herein, such as control of arm position and providing feedback. Section headings are provided for assistance in navigation and should not be considered as necessarily limiting the contents of the section. When used in the following claims, the terms "comprises", "includes",  
25 "have" and their conjugates mean "including but not limited to". It should also be noted that the device is suitable for both males and female, with male pronouns being used for convenience.

It will be appreciated by a person skilled in the art that the present invention is not limited by what has thus far been described. Rather, the scope of the present invention is  
30 limited only by the following claims.